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INTERIM REPORT NO. 3

RESEARCH AND DEVELOPMENT
OF
CACHE MARKER SYSTEM

PHASE II: DEVELOPMENT OF ENGINEERING
PROTOTYPE

Covering the Period:
15 April 1953 to 15 June 1953

Contract No.

21 July 1953

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ABSTRACT

1. Field tests of the Q Meter detection system using a single tuned circuit as a transponder demonstrated the ability to detect the transponders at a horizontal distance of six feet. The transponders were buried five feet below the earth's surface.
2. The effect of distributed capacity on the detection coil was greatly reduced by use of a Faraday shield without any observable reduction in sensitivity.
3. The various methods and materials that are being considered for the packaging of transponders are described.
4. An experiment on the measurement of attenuation in salt water is described. The results indicate excessive attenuation would be encountered for a cache marker system utilizing a tuned circuit transponder in sea water.

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SECURITY INFORMATIONI. Field Tests

The tests to demonstrate the ability to use a tuned circuit as a transponder for the cache marker system were carried out during this interval. The experiment using the Q Meter detection system demonstrated the ability to detect the transponder at a horizontal distance of approximately six feet with the transponder buried at a depth of five feet.

The site was prepared by digging trenches two feet wide, five feet deep and about twenty feet long. After the transponder was placed in the bottom of the trench, the trench was completely refilled with dirt and the measurements were taken. The site chosen was flat so that there could be no doubt as to the distance and path of the electromagnetic radiation.

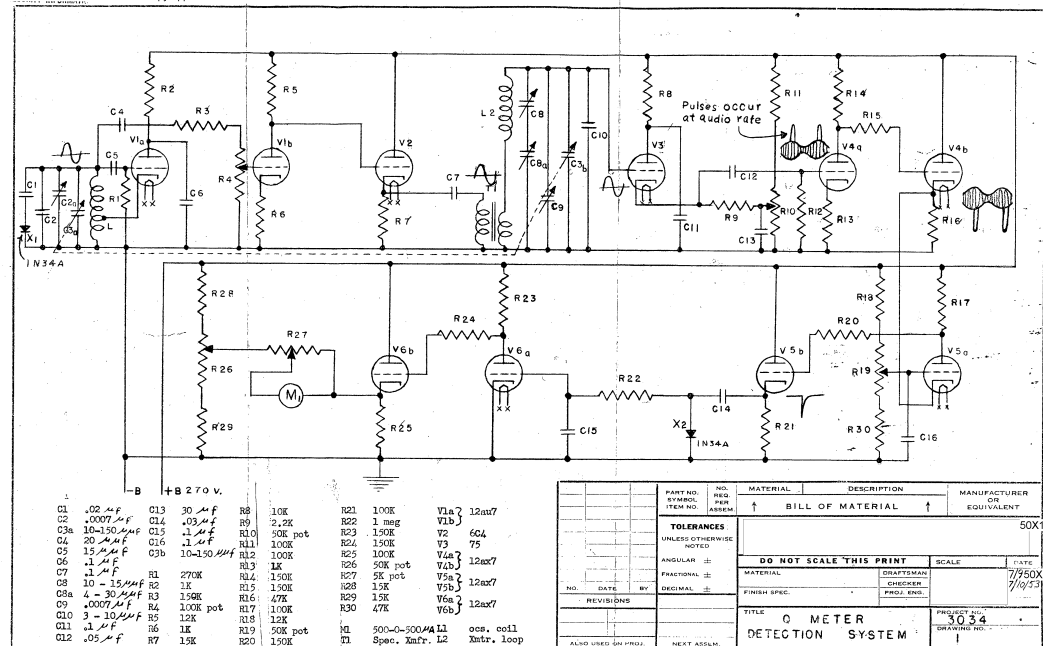
The transponders used for this experiment were prepared for burial in the ground in two ways. One transponder was encased in a Plexiglass case which was made from sheet stock. The other method consisted of casting the coil in white synthetic ceresin wax. This particular wax has excellent electrical properties in that the dielectric losses are extremely low accompanied by a low dielectric constant. The melting point varies between 165°F to 170°F with a softening point at 135°F.*

An incident occurred during the field test which gave some indication of the mechanical properties of wax. A ditch digger was used to remove the dirt to recover the transponders after the tests. In moving the ditch digger into position, one of the tracks ran over or pushed aside two transponders which

* These values were obtained from Fisher Scientific Company and Reference Data for Radio Engineers, 3rd Ed., p. 52.

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$C3_a$ and $C3_b$ are ganged together to form the main tuning control. The tracking of the frequency of the oscillator and the series resonant frequency of the detection circuit must be sufficiently accurate to prevent sudden decreases in output as the tuning control is varied. $L1$ is a slug tuned inductance which can be adjusted until it matches $L2$. $C2_a$ can be adjusted so that the tracking error, in terms of capacity, is about 1mmf. This number of adjustments allows the tracking error to become that of the tuning capacitors alone.

If all the adjustments are made properly, it is possible to bring the circuit containing $L2$ into exact resonance with the driving frequency by a slight adjustment of $C10$ for all positions of the main tuning control. A method for doing this automatically was devised.

The motor driven variable capacitor $C8$ was added in series with $C8_a$. $C8$ is a capacitor designed for 360° rotation with a capacity change of about 15mmf from maximum to minimum capacity. $C8_a$ is a 4-30mmf trimmer which reduces the capacity change to about 3mmf. This change in capacity is sufficiently large to take care of the tracking error. As the motor driven capacity varies from a minimum to a maximum, there is always a position where the resonant frequency of the detection coil is exactly the same as the frequency of the driving circuit.

The signal which appears across $L1$ is thus amplitude modulated at the rate at which the capacity passes through the value needed for resonance. This signal passes through the "window" amplifier, is detected, filtered and applied to a meter circuit which responds to the changes in peak amplitude.

One of the observations made during the field tests indicated that

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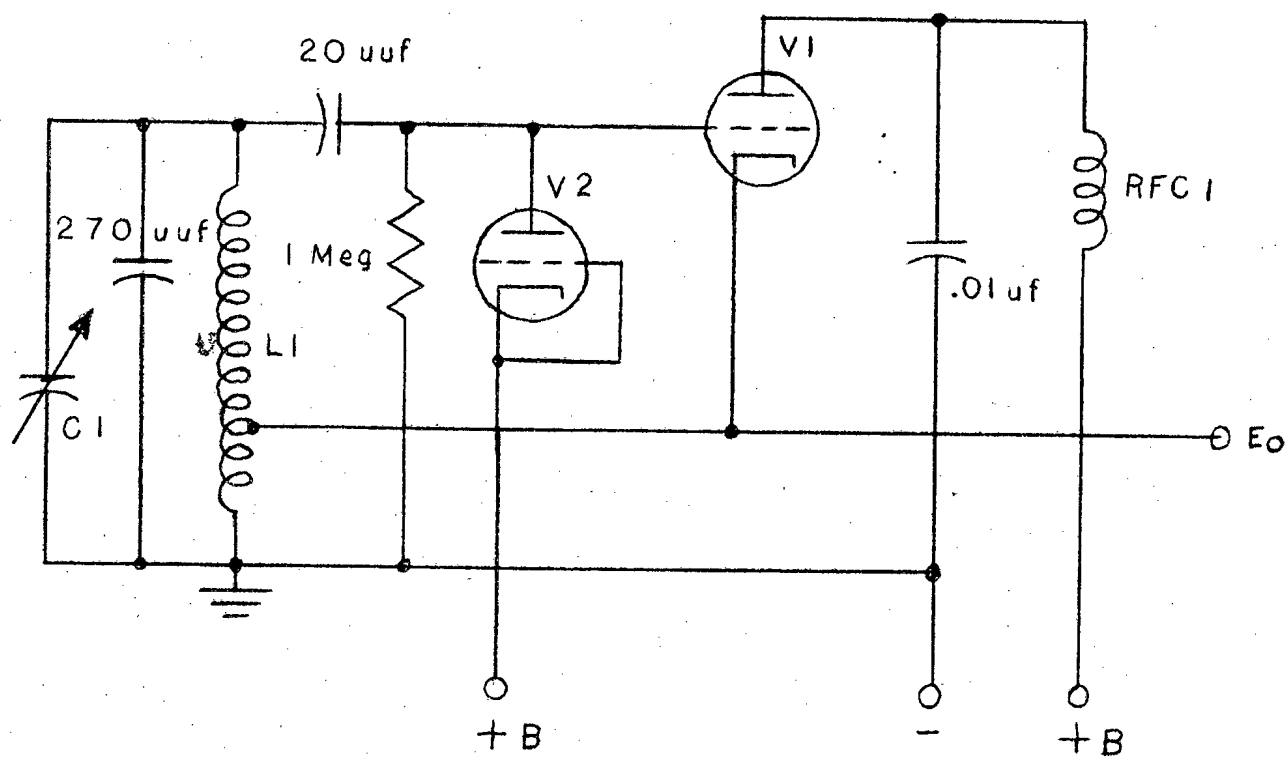
the capacity, with respect to ground, of the detection coil was of sufficient magnitude so that slight changes of the detection coils orientation with respect to ground detuned the system. It was found that the distributed capacity could be reduced by the use of a Faraday shield constructed out of No. 24 wire imbedded with wax on a cardboard sheet completely covering the coil. It was found that the effects of the hand capacity were greatly reduced when this shield was connected to the ground of the detection system. The ability of the detection system to detect the presence of the transponder is not reduced by an observable amount when the shield is connected. This type of shield differs from the shields used on previous occasions which were of the kind found in direction finders.

The reliability of the Q Meter detection system depends largely on the amplitude and frequency stability of the oscillator. The amplitude stability determines the amount of amplification that can be used in the "window" amplifier and, thus, the ultimate sensitivity of the system. The same holds true for the frequency stability of the oscillator. Frequency stability is also important from the standpoint of being able to set the detection system to the known frequency of the transponder. Three circuits were investigated to determine their amplitude and frequency stability.

The first oscillator to be tested was the Hartley oscillator. The circuit is standard with the exception of a positively biased diode from grid to ground (see Figure 2). This reduced the variation in amplitude with frequency from a total change of two volts peak to peak to a change which could not be measured using the Type 512 Tektronix scope. The frequency drift was

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$L1$ 2.5 mh.
 $Rfc1$ 2.5 mh.
 $V1$ } 12AU7
 $V2$ }
 $C1$ 10-280 uuf

FIG. 2

THE STABILIZED HARTLEY OSCILLATOR

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too large to be measured by using a Lisseajous figure.

The second circuit that was tested was a series tuned Colpitts, or Clapp, oscillator (see Figure 3). This circuit is noted for its frequency stability. With a change of 100% in the plate voltage, the frequency changed only 1.5 cycles at 240kc. The change in amplitude as the frequency was varied was not measurable.

The last circuit that was tested was the Franklin oscillator which is shown in Figure 4. This circuit is also noted for having good frequency stability, but with 100% change in plate voltage the frequency changed by 10 cycles. No measurable change in amplitude was observed when tuning over a 20kc range at 100kc.

Of the three circuits that were tested, either the Clapp or the Franklin oscillator is suitable for our needs. No tests were made to determine frequency changes due to changes in temperature.

III. Transponders

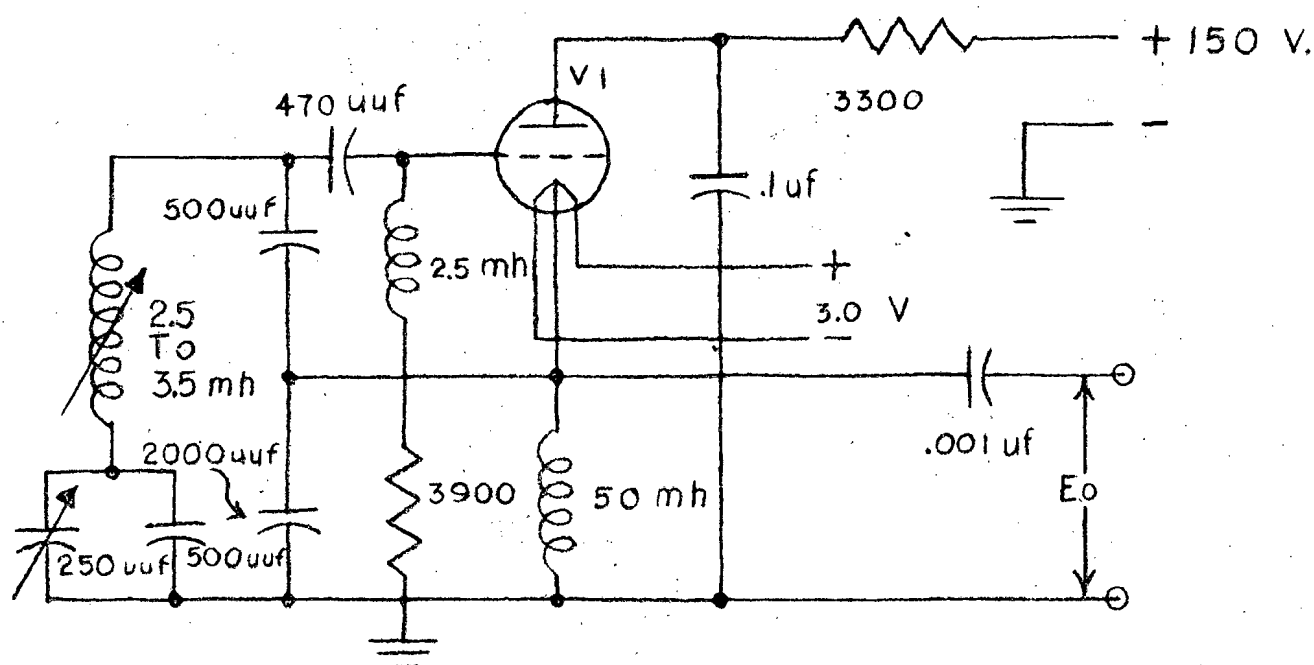
The sponsor of this contract has requested that 25 transponders be built and delivered in about three months. Transponders tuned to five different frequencies, five transponders for each frequency, are to be constructed. The outside diameter will not be greater than 15 inches. Several kinds of packaging, discussed below, will be used. For each frequency one or more transponders will be made according to each technique discussed.

The activity in connection with transponders has largely been concerned with obtaining information on the various materials that are being

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Resistor values in ohms.
 V1 1/2 3A5

FIG. 3

THE CLAPP OSCILLATOR

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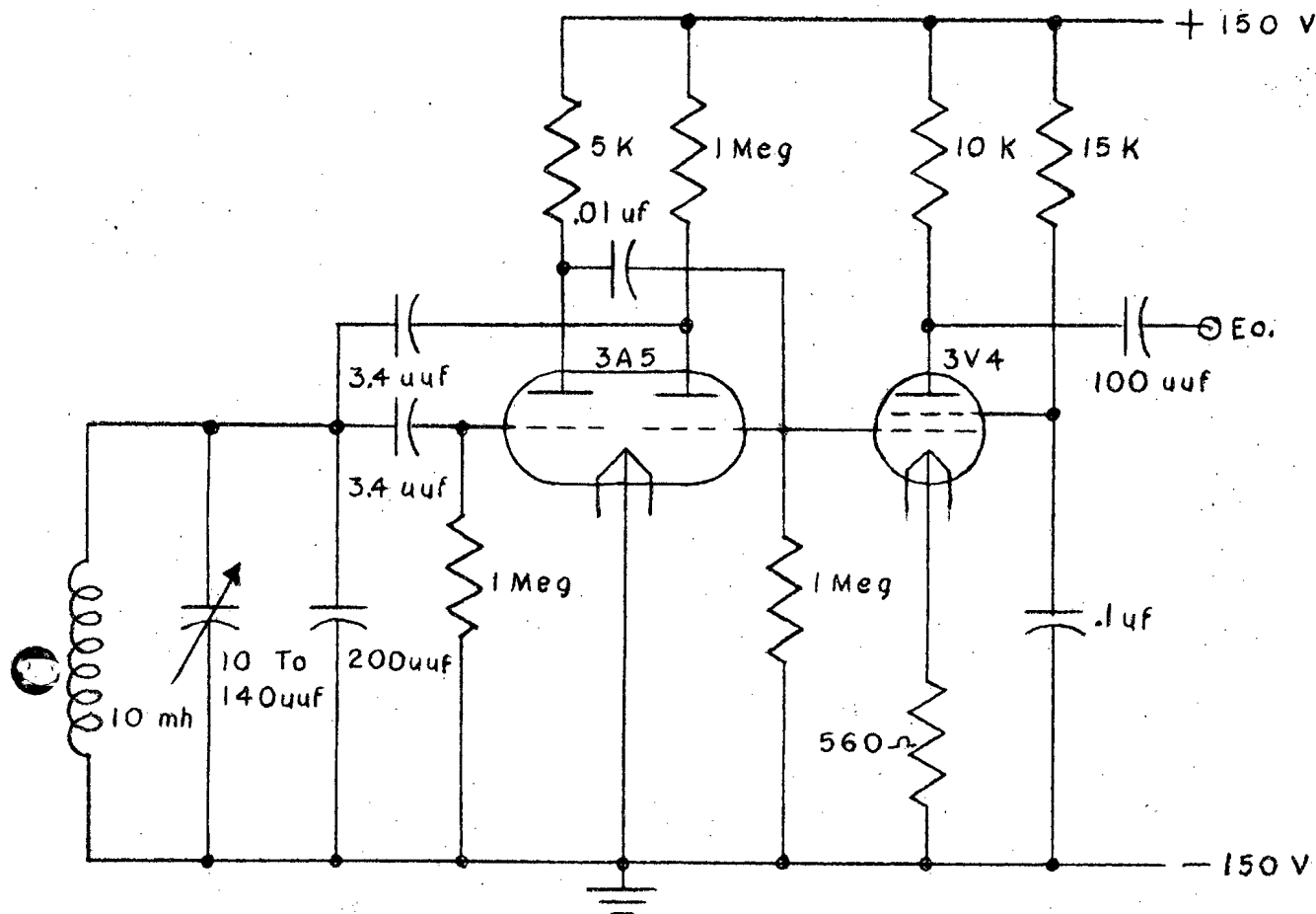


FIG. 4

THE FRANKLIN OSCILLATOR

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considered for packaging and with various ways of packaging. The doughnut shape has been favored because of the form of the coil, although some thought has been given to a disc-shaped transponder.

The large success enjoyed by the use of ceresin wax prompted us to investigate other waxes. The synthetic ceresin wax used costs 80 cents per pound in small quantities; eight pounds is used for a transponder of the 17 inch O.D. size. Socony Vacuum Oil Company makes a wax called Cerese, costing $14\frac{1}{2}$ cents per pound, which has excellent mechanical and electrical properties. It is a tough microcrystalline wax that melts above 170°F. It is non-hygroscopic and is used as a waterproofing material. It is resistant to oxidation and to exposure to moisture so that little deterioration or loss of electrical properties results on aging. The Q of a coil cast in Cerese AAA wax was compared with the same coil in air giving the following :

Table I. Coil Characteristics

<u>Frequency</u>	<u>In Air</u>		<u>In Cerese AAA</u>	
	<u>Q</u>	<u>C</u>	<u>Q</u>	<u>C</u>
200kc	290	258(mmf)	235	230(mmf)
175kc	325	347	260	315
155kc	350	458	290	423
125kc	320	718	280	678
100kc	370	1128	340	1083
89kc	380	1450	350	1385
68kc	380	2450	350	2387

The first column gives the frequency at which the measurements were made. The next two columns give the Q and capacity in air and the last two columns give the same measurements after the coil was cast in wax.

The percentage reduction in Q is greater at the higher frequencies,

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probably because the increase in distributed capacity is a larger percentage of the capacity needed to resonate the coil at the higher frequencies. The Q increases with decrease in frequency. The measurements of Q below 150kc are low by about 17% due to harmonic distortion in the Boonton Q Meter oscillator on this band. On the whole the decrease in Q does not significantly alter the operation of the transponder.

The same process of casting the coil in a solid block of material can be carried out using a casting resin having good electrical and mechanical properties. One material that is being considered is the AN-5 casting developed by Dr. Max Lee of the National Bureau of Standards. This material is a polyester type resin which has excellent electrical properties; the dielectric constant (≈ 2.5) is low, the power factor (.001) is extremely low, and the moisture absorption (.01%) is also very low. This material is not available commercially, and we are having Atlantic Research Corporation of Alexandria, Va. make up a sample batch of five gallons.

The specific gravity of both the Cerese wax and AN-5 casting resin is approximately unity, and a solid casting weighs about 10 pounds. In order to reduce the weight several different structures and materials are being considered.

The foam-in-place plastics seem ideally suited for the purpose of encapsulating the transponder. These plastics have a sponge-like structure but can be made to have a wide range in compressive strength. The density depends on the compressive strength required; to withstand 30 pounds per square inch pressure a density of six pounds per cubic foot is required in Lock foam.

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Nopco Chemical Company of Harrison, New Jersey, is sending samples of this material in both the liquid and foamed form for evaluation. Because of the porous structure of the foam-in-place plastics, a protective coating or covering is needed for protection against moisture absorption. This can vary from a shell structure, fabricated separately, to a protective coating.

The material we are considering for this shell structure is Laminac reinforced with fibreglass mat. Laminac is an inexpensive polyester type casting resin with good mechanical and electrical properties, manufactured by the American Cyanamid Company. If small numbers only are required, the shell structure can be made by a "hand-lay-up" technique, using plaster of paris molds. Two other methods, the vacuum bag technique and matched metal mold technique, are suitable for large quantities. The latter is about three times as fast as the former but more expensive.

It appears that a protective coating put on by a dip or spraying process would be simpler than the above and thus cheaper to use. The plastisols appear to be a possibility for this technique. We are also considering the use of a film of polyethylene which is a thermoplastic material and can be sealed by the application of heat and some pressure.

The transponders built thus far have been wound on a coil form fabricated of a Plexiglass rim with polystyrene rods. In production these forms should be molded in one piece, and this problem is being presented to companies who make molds and do plastic molding. The other possibility is to treat the coils in such a manner that they can be slipped off the forms and be self-supporting. Removable steel pins are being made for this purpose.

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To facilitate testing the transponders in the laboratory, a wooden box 4 x 4 x 2 feet was built. No metal was used in its construction. Another container $2\frac{1}{2} \times 2\frac{1}{2} \times 2/3$ feet was placed inside the first container, and the space between the two was filled with sand. The inner container allows easy burial and removal of the transponder. The containers were made watertight so that the effect of moisture could be observed. In some of the tests the inner container was filled with water and the transponders, imbedded in wax, were immersed. The high dielectric constant of water decreased the frequency, but there was no observable change in the ability to detect the transponder as compared to air.

This setup permitted measurement of the effect of a salt water transmission medium with the experimental arrangement shown in Figure 5. The output of the detection system was displayed on a Tektronix scope. Ordinary rock salt was added a pound at a time, and the change in signal was observed as the detector was tuned through the resonant frequency of the transponder. The results are given in Table II.

Table II

<u>Pounds of Salt</u>	<u>Specific Gravity</u>	<u>Amplitude Change</u>	<u>L</u>
0	1.000	1/2cm	9
1	1.005	1/2cm	9
2	1.010	1/3cm	9'
3	1.014	1/4cm	9
4	1.019	1/8cm	9'
4	1.019	2/3cm	7'
5	1.023	1/2	7'
6	1.028	1/2	7'
7	1.032	1/2	7'
8	1.037	1/3	7'
9	1.042	1/3	7'
10	1.046	1/4	7'

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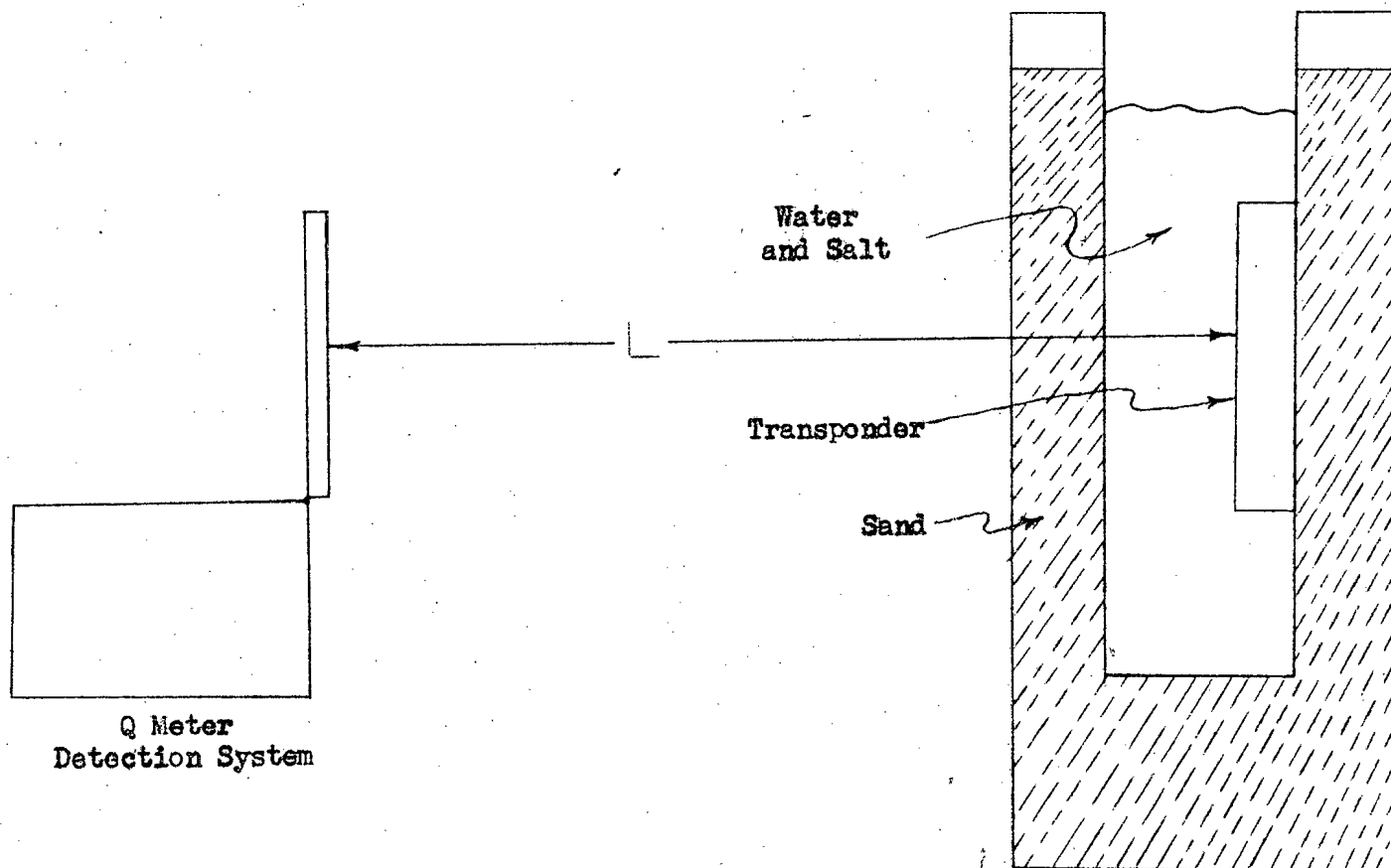


Figure 5.

Arrangement for Measurement of Attenuation of Salt Water

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The specific gravity of sea water ranges in value from 1.025 to 1.027. The round trip through the salt water was about one foot out of a total path of 18 feet or 14 feet, so that the actual transmission through salt water was only a small percentage of the total path. The specific gravity for five to six pounds of salt covers the range encountered in sea water. For this amount of salt the indication obtained at seven feet was the same as the indication at nine feet with no salt in the water. This is a reduction in signal of about $1/5$, allowing for the fact that the reflected signal drops off as the sixth power of the distance. An experimental check of this power for the attenuation can be obtained from the data for four pounds of salt at distances of seven and nine feet. From these results it appears that severe attenuation is to be expected in sea water.

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